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HS 2324+3944: discovery of non-radial pulsations in a hydrogen-rich PG 1159 star ⋆

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Abstract. HS 2324+3944 is a peculiar PG 1159 star, with a high amount of H in its atmosphere (Dreizler et al. 1995). Its location in the $\log T_{\rm eff} - \log g$ plane is well inside the GW Vir instability strip. In this paper I report the results of two photoelectric observations of HS 2324+39, which clearly show that the luminosity of this star presents periodical variations with a period of (2140 ± 11) s. This photometric behaviour is most easily explained by the presence of non-radial oscillations. Therefore HS 2324+39 is a new member of the GW Vir group, and is characterized by the longest pulsation period found among these stars. Moreover HS 2324+39 appears to be the first pulsating PG 1159 star with a high H abundance in its atmosphere (H/He = 2 by number, Dreizler et al. 1995). Were the pulsation mechanism based on the C/O cyclic ionization (Starrfield et al. 1984) at work, the H abundance should drop to zero sharply in the driving regions. Such a strong decrease of hydrogen looks quite unlikely; for this reason the presence of pulsations in HS 2324+39 seems to be a very interesting phenomenon.

Key words: stars: post–AGB - stars: oscillations - stars: individual: HS 2324+3944

1. Introduction

HS 2324+3944 was recognized analyzing the Hamburg Schmidt Survey plates (Hagen et al. 1995, Wisotzki 1994). It has been classified as a lgEH PG 1159 (Dreizler et al. 1995), following the scheme of Werner (1992). Dreizler et al. (1995, hereafter DWHE95) have made a detailed analysis of the spectral characteristics of HS 2324+39; here is a brief summary of what they have found. HS 2324+39 is a "hybrid PG 1159 star", showing H Balmer absorption features in its spectrum, and it is the only "hydrogen PG 1159" not surrounded by a planetary nebula. The high H abundance (H/He = 2.0 $^{+0.5}_{-0.6}$ by number) is about 10 times the upper limit found by Werner (1995) for PG 1159–035! The abundances of He, C and N (C/He = 0.3, N/He < 0.002) are "normal", whereas the O abundance (O/He = 0.006 ± 0.004) is quite low respect to the "standard" PG 1159 stars (O/He = 0.13 for PG 1159–035). The effective temperature is equal to (130 000 ± 10 000) K; the surface gravity, corresponding to $\log g = 6.2 \pm 0.2$, is one of the lowest for the PG 1159 stars without nebula. In fact, HS 2324+39 is located in a region of the $\log T_{\rm eff} - \log g$ plane where most objects are central stars of planetary nebulae (CSPN) (DWHE95 Fig. 5).

With these values for temperature and gravity, HS 2324+39 results to be well within the GW Vir instability strip. Presently the group of the GW Vir stars is formed by 13 objects [1] (9 CSPN, 4 not showing a nebula), whose luminosity has multi-frequency variations, due to the presence of non-radial g-mode pulsations (Bradley 1995, Silvotti et al. 1995 and references therein). The typical values of the pulsation periods are 10–35 minutes for the variable CSPN (also called PNNV), and 5–15 min for the pulsating stars without nebula (also called DOV).

The driving mechanism proposed to explain the pulsations in all these stars is the $\kappa - \gamma$ mechanism, based on the C/O cyclic ionization (Starrfield et al. 1984). It has been shown (Stanghellini et al. 1991) that even a small amount of H in the driving layers can be sufficient to inhibit the pulsation mechanism. Such a high sensitivity to the chemical composition could in principle explain why not all the PG 1159 stars do pulsate.

Now the high H abundance of HS 2324+39 would suggest that no pulsations are possible for this star. Therefore the presence or the absence of pulsations in HS 2324+39

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⋆ Based on observations obtained at the Loiano Observatory, Italy.

[1] We refer here to the "pulsational definition" of the GW Vir stars; from spectroscopy the GW Vir stars are only 8 (4 with nebula, 4 without), the remaining 5 pulsating CSPN are early WR stars.

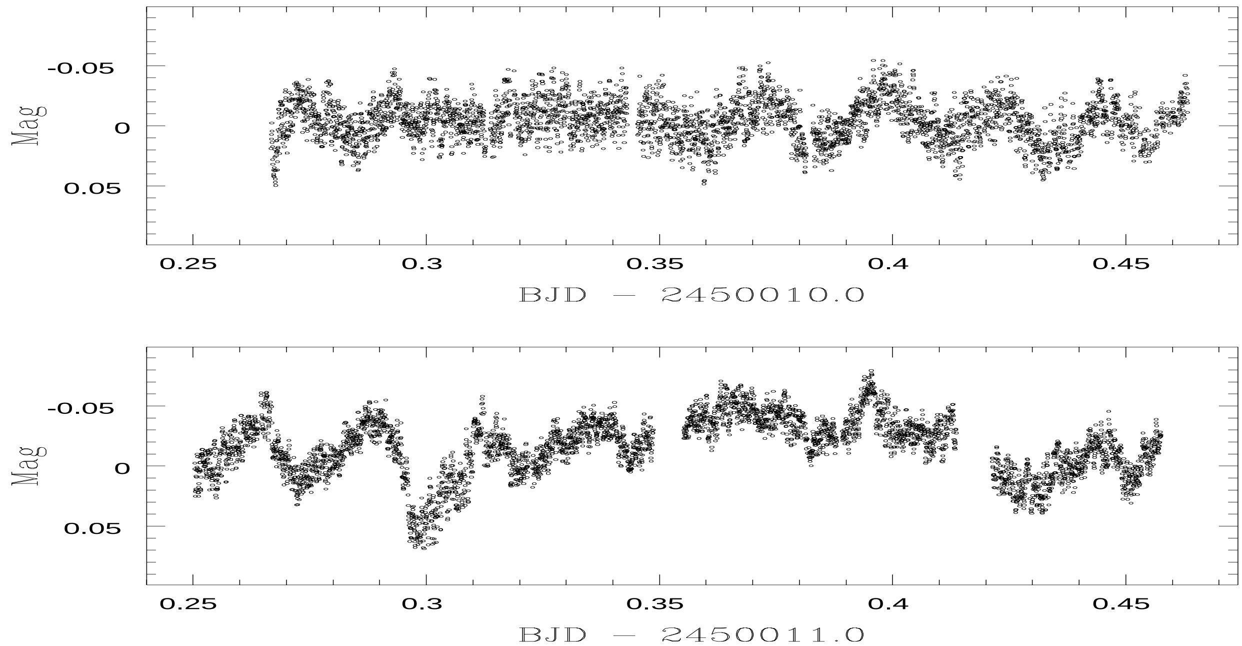

Fig. 1. Light curves of HS 2324+3944 in October 19 and 20, 1995

seemed to be an interesting test for the GW Vir pulsation mechanism. For this reason I decided to investigate on the variability of HS 2324+39. The results of two photoelectric observations of this star are presented in the following section of this paper. A preliminary communication on the variability of HS 2324+39 has been already published (Silvotti 1995).

2. Observations and results

I observed HS 2324+39 with the 2-head photoelectric photometer (Piccioni et al. 1979, Bartolini et al. 1993) of the 1.5 m Loiano telescope (Italy) on October 19 and 20, 1995, with no moon. The tubes used, two EMI 9784 QB, have a maximum sensitivity in the B band. Both observations were carried out without filter, with an integration time of 2 s. The comparison stars of the two observations were different (Silvotti 1995). The light curves of the target and the comparison star for the two nights are shown in Silvotti (1995). Here I have selected the best curves, i.e. the difference of magnitude between target and comparison star for the 19/10 observation, and HS 2324+39 alone for the 20/10 observation. The light curves are shown in Fig. 1, where each point represents a 4 s integration (the data were binned bringing the effective integration time from 2 to 4 s). In both light curves we can see several arc features with a mean period of about half an hour. The quiescent zone in the light curve of October 19 (Fig. 1 from about 0.3 to 0.35 fractional Barycentric Julian Day (BJD)) could be caused by the interference of different frequencies.

From the discrete Fourier transform of the best night (19/10) we obtain a period of (2130 ± 70) s, with an amplitude of 10 mmag. The amplitude spectrum is presented in Fig. 2, together with the spectrum of a sinusoid with the same time distribution, same period and same amplitude (spectral window). If we make the discrete Fourier transform of both nights together (32 % duty cycle), the main peak is at about 2130 s (amplitude 10 mmag), in very good agreement with the values obtained on the first night. Things are a bit different considering the second night alone: the spectrum shows two peaks at (2220 ± 80) and (1890 ± 50) s. The amplitudes, which are respectively 14 and 12 mmag, are probably increased by the sky noise [2]. It is not clear whether these two periodicities are real or not. The higher period (2220 s ± 80) is not incompatible with the value found on the first night (2130 s ± 70). In any case it is easy to verify that the data of the two successive nights are in phase, and can be very well folded

[2] The data of the second night were reduced using only the counts of the target. I adopted this procedure because the comparison star was gone off the aperture for about one hour (Silvotti 1995). In any case, even using the difference of magnitude between target and comparison star, the light curve does not change significantly. The reason is that the comparison star is about 2 magnitudes brighter than HS 2324+39. Therefore channel 2 effectively compensates only for the transparency variations, not the sky variations. The best solution to this problem is certainly to use a 3 channel photometer. If only a 2 channel photometer is available, the best thing to do is probably to choose a comparison star having about the same magnitude as the target, as it was done in the second observation of HS 2324+39. In this manner both the transparency and the sky variations during the night can be partially compensated for.

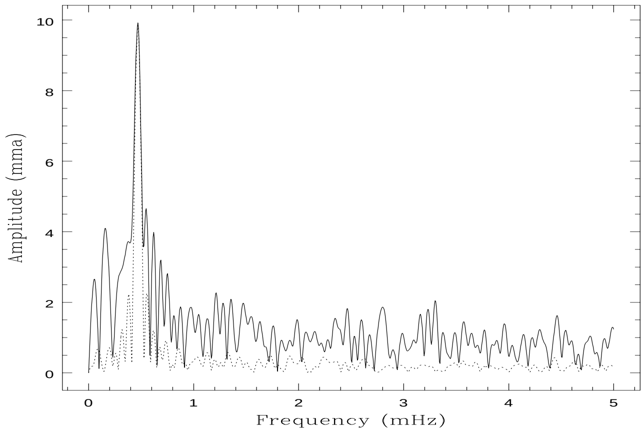

Fig. 2. Amplitude spectrum (solid line) and spectral window (dot line) of HS 2324+3944 on October 19, 1995

over a single frequency (Fig. 3). In this hypothesis, namely that the luminosity variations of HS 2324+39 are due to a single pulsation frequency, we obtain the following best pulsation period P:

$$P = (2140.5 \pm 11.0)\, s$$

The error has been estimated considering:

$$\frac{\Delta P}{P} = \frac{1}{4} \times \frac{1}{number\, of\, phased\, cycles}$$

The times t_{min} of the minima are given by:

$$t_{min} = [2450010.28540 \pm 0.00100 + n\,(0.02477 \pm 0.00013)]\, BJD$$

From Fig. 3 (upper part) the average shape of the pulse appears to be slightly asymmetric, with the descent steeper than the climb.

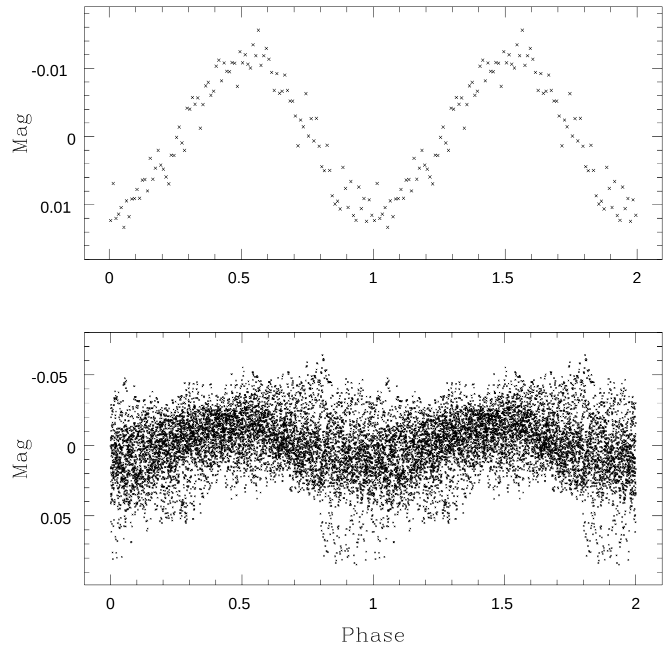

Fig. 3. The two observations of HS 2324+3944 folded over a period of 2140.5 s. The top panel is obtained dividing the phase in 100 equal intervals and taking the mean magnitude

3. Summary and discussion

HS 2324+39 is a new H-rich peculiar PG 1159 pulsating star. It seems to be a very interesting object for several reasons:

1. it is, so far, the only PG 1159 pulsating star with a high H abundance in its atmosphere (He/H=0.5 by number, DWHE95). This fact seems to be in contrast with the C/O pulsation mechanism proposed by Starrfield et al. (1984), unless we admit that the H abundance drops to zero sharply in the driving regions. The hydrogen could be maintained in a thin surface layer by the gravitational settling. This hypothesis would imply some limits to the strength of the stellar winds and to the extension of the surface convection zone. A weak stellar wind is also suggested by the shape of the blue part of the C IV components near 4650 Å in the spectrum of HS 2324+39 (DWHE95 Fig. 4, Leuenhagen 1995).

The edges of the theoretical GW Vir instability strip obtained by Starrfield et al. (1984) and by Stanghellini et al. (1991) are calculated using the Los Alamos opacities. Starrfield et al. (1984) considered only carbon and oxygen in the surface, whereas Stanghellini et al. (1991) contemplated also the presence of helium. The presence of hydrogen was never considered. The most realistic models, with 50 % carbon and 50 % helium by mass (Stanghellini et al. 1991), are pulsationally unstable at effective temperatures much lower than the real GW Vir stars. More recently Saio (1996), using the OPAL opacities, has obtained overstable modes in models with a surface composition closer to the real GW Vir stars (Y=0.38, X_C=0.4, X_O=0.2, Z=0.02). A model sequence with a 3 % (by mass) abundance of hydrogen was also computed; the stability of g-modes results to be hardly affected by the existence of hydrogen. The chemical abundances obtained by Werner (1995) for PG 1159–035 (X<0.015, Y=0.32, X_C=0.48, X_O=0.165, taking Z $\simeq$ 0.02) are quite similar to those used by Saio (1996). But for HS 2324+39 (X=0.20, Y=0.405, X_C=0.365, X_O=0.01, DWHE95 considering Z=0.02) things are quite different: the H and O abundances, compared with PG 1159–035, are in practice exchanged. Nevertheless, the location of HS 2324+39 in the $\log T_{\rm eff} - \log \Pi$ diagram of Saio (1996, Fig. 5) is consistent with models having stellar masses between 0.58 and 0.60 $M_\odot$, in good agreement with the value of 0.59 $M_\odot$, obtained by DWHE95 comparing the lo-

cation of HS 2324+39 in the $\log T_{\rm eff} - \log g$ plane with evolutionary tracks.
2. The pulsation period of (2140 ± 11) s is the longest ever observed in a PG 1159 star.
3. The duration of the pulsation period and the position of HS 2324+39 in the $\log T_{\rm eff} - \log g$ plane (DWHE95) would suggest the presence of a planetary nebula (PN) around the star. Moreover all the other H-rich PG 1159 stars are CSPN. Presently it seems that HS 2324+39 does not have any PN remnant. A recent observation made at Calar Alto (Werner 1996) confirms this thesis.

For all these reasons, a detailed study of the HS 2324+39 pulsation should be undertaken. With precision asteroseismology some open questions regarding the structure and the mass of the external layers of HS 2324+39 could be solved. The best way to achieve this purpose would be to observe HS 2324+39 with the Whole Earth Telescope (Nather et al. 1990). The peculiar characteristics of HS 2324+39 make this star very interesting and give us a possibility to improve our knowledge on the GW Vir pulsation phenomenon.

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